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Optimal Sampling Strategies for Point-to-Point Line-Of-Sight Calculations in Urban Regions

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Summary: Smartphone applications are driving a growing interest in 3D modelling – in particular the use of LiDAR for modelling city landscapes at high levels of precision and accuracy. In such dynamic environments, where we wish to make decisions based on places of interest that are in the (rapidly changing) field of view, it is critical that we address performance issues in visibility analysis. This paper explores optimisation of a point-to-point line-of-sight algorithm, outlining a variety of line of sight sampling strategies, together with a number of trials that enabled us to optimise sampling in the context of urban visibility analysis.

KEYWORDS: visibility analysis, vista space, LBS, 3D modelling

1. Introduction

People describe and explore space with a heavy emphasis on the visual senses, yet Location Based Services (LBS) under utilise this as a search parameter (May, Ross et al. 2005), relying instead on proximity in Euclidean or network space. For an urban LBS application to include vista space (Montello 1993), that which can be seen from a static location with only movements of the observer's head, an urban elevation model which includes topography and surface objects is required. Light Detection and Ranging (LiDAR), provides an economically viable solution, as has been previously demonstrated in urban areas (Palmer and Shan 2002; Rottensteiner and Briese 2002; Bartie and Mackaness 2006).

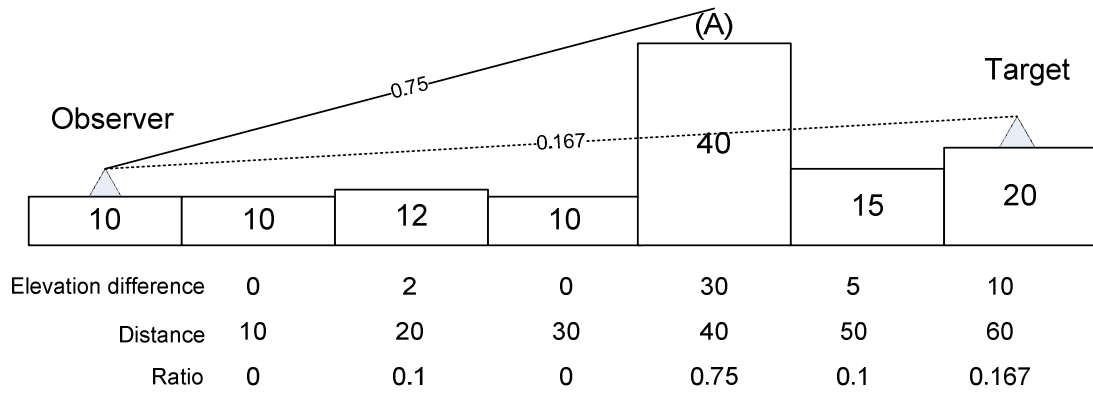
The computational efficiency of Isovist (Tandy 1967; Benedikt 1979; Turner, Doxa et al. 2001) and viewshed (Tandy 1967; Lynch 1976) models has received much attention (De Floriani, Magillo et al. 2000; Rana and Morley 2002; Rana 2003; Ying, Li et al. 2006). However in some cases it is not necessary to compute the visibility of regions, but instead to determine the visibility of a single point or a small set of points. For example to allow an LBS application to alert a user when a friend is somewhere in view

requires only the point locations for the two LBS users. Similarly to determine if an upcoming junction is visible, or not, for inclusion in way-finding instructions (Bartie and Kumler 2010) requires only the position of the user and the junction. In other applications, such as for security surveillance, the analysis may be limited to a set of points along a linear feature, such as a boundary fence. In addition a rapid approximate object visibility (e.g. a building) may be estimated by calculating the visibility to a limited set of very important points which define its structure, such as roof ridge lines and outer walls (rather than a large cloud of points).

This research explores how performance improvements can be gained in point-to-point line-of-sight calculations through the re-ordering of sample locations. The paper takes the form of a short introduction to the line of sight (LOS) model, before exploring a variety of LOS sampling strategies. The method which shows the biggest performance improvement is then tested in three UK cities to compare results.

2. Line of Sight Calculation

The basic line-of-sight algorithm as described by Fisher (1993) compares the vertical angle created from an observer to a specified target at another location, against the vertical angles from the observer to all cells in between. If any intermediate cell creates a viewing angle greater than that of the observer to target angle, then the target is considered to be not visible (Figure 1). The assumption here is that the target is considered to be visible until proven otherwise, and that the angle from observer to target is the first calculation to which all other angles are compared. As soon as an intermediate viewing angle is calculated above that of the target, then the search may be aborted as the target has been shown to be obscured from the observer.



The ratio from the Observer to A is greater than Observer to Target, therefore target is not visible

Figure 1: A Line of Sight Approach

If every terrain cell in a line-of-sight path is considered between an observer and target it is referred to as the ‘golden case’ (Rana and Morley 2002), but for a Boolean point-to-point visibility result these intermediate values are not required. The scan order can therefore be modified to test any intermediate cell, and determine if the target is blocked from view. If it is not blocked then another intermediate cell should be tested, repeating this until either all cells along the line-of-sight have been checked and the target is considered visible, or if at some point the target is below the current viewing angle it is deemed to be out of sight and the checking of other intermediate cells can be terminated. The question is: can the algorithm be made more efficient by considering different sampling steps and different orderings?

3. Line of Sight Sampling

There are a number of ways that the raster Digital Surface Model (DSM) cells between an observer and target can be sampled. These include using a vector ray which is sampled at given intervals along its length (Figure 2a), and a raster approach using the Bresenham's line algorithm, which selects the cells in order along a path from an observer to a designated target (Figure 2b).

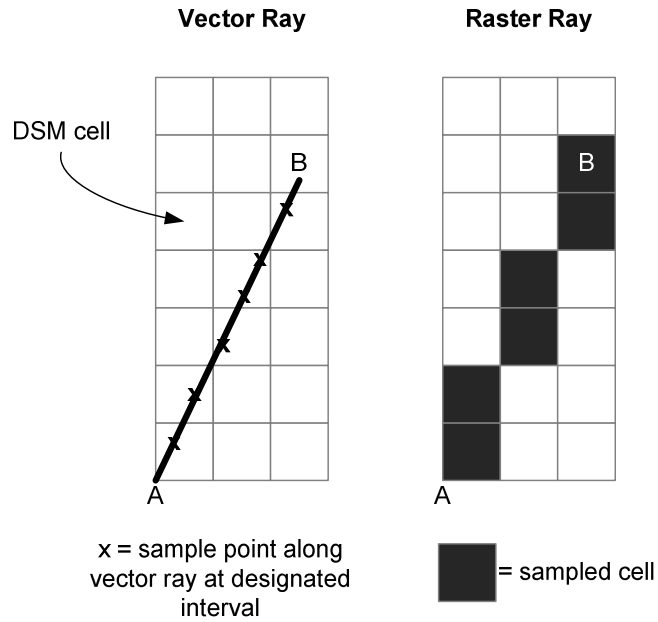


Figure 2: Cell Sampling Approaches based on Vector(2a) and Raster Lines (2b)

Modifications to the sampling order should enable performance improvements in scenarios where the early set of samples can rule out the visibility of the target. The vector approach was found to be more computationally efficient at this task, and allowed for easier search order modifications. The orders implemented were (a-f):

- a) Straight Ordering – eg 1234567
- b) First, Last Ordering – eg 1726354
- c) Divide and Conquer A – eg 1742635
- d) Divide and Conquer B – eg 4267531
- e) Reverse Ordering – eg 7654321
- f) Hop of Length N – eg (when N=2) 1357246

A number of trials were conducted whereby the processor execution time was measured, removing variations resulting from other OS background processes. All data was loaded into memory at the start of the experiment to remove variations from disk activity. These experiments were conducted on a DSM of 1 metre resolution for the city of Edinburgh, Scotland

4. Trial 1 – Single Point to Point

A pair of points 1200 metres apart was defined for a case where it was known that the observer could view the target. To increase the workload the same visibility test was carried out 5000 times in succession.

As expected the results (Table 1) indicate no performance benefit in the alternative approaches, as all intermediate cells have to be sampled when the target is visible. The re-ordering computational overhead impacts methods C, D while other methods exhibited similar calculation times to the original order (A). This table therefore gives an indication of algorithm efficiency for the golden case.

Table 1: Visibility Trial for True Case

| Order | A | B | C | D | E | F (N = 5m) |
|------------|------|------|------|------|------|---------------|
| Time (sec) | 6.67 | 6.52 | 8.60 | 9.10 | 6.71 | 6.41 |
| % of A | 100 | 98 | 129 | 136 | 99 | 96 |

Another trial was conducted where the target was out-of-sight. This time the benefits of changing the sampling order were obvious (Table 2), with alternative orders resulting in reduced calculation times.

Table 2: Visibility Trial for False Case

| Order | A | B | C | D | E | F (N=5m) |
|------------|------|------|------|------|------|-------------|
| Time (sec) | 1.83 | 0.34 | 0.74 | 0.52 | 0.71 | 0.62 |
| % of A | 100 | 19 | 40 | 28 | 39 | 34 |

To ensure the benefits noted in this single trial held across multiple test location pairs, further trials were conducted.

5. Trial 2 – Multiple Observer-Target Pairs

For the second set of trials 1000 locations were selected randomly across the East side of Edinburgh, with the restriction that they must be in pedestrian accessible locations (i.e. on streets, open spaces, and not on roof tops).

The trial involved testing the visibility from each point to all others, resulting in 1 million visibility tests. The trial was conducted in two ways, firstly with the sample orders being calculated live, and secondly with access to pre-calculated sample orders available from a memory cache. This second approach negates the computation time of calculating the sampling order, but does introduce a minimal cache search and access time. The cache stores the search order for every distance in increments of 1 metre, up to a maximum of 5000m. A check was carried out after each trial to ensure the same results were determined in each case. The calculations were not reversible as an elevation offset of 1.8 metres was applied to the observer, and 0.5 metres to the target. The results from these trials are shown in Table 3.

Table 3: Trial 2 Results - Live and Pre-cached Sort Orders

| Order | A | B | C | D | E | F (N=5m) |
|---------------------|--------|--------|--------|--------|--------|-------------|
| Live (seconds) | 160.03 | 201.83 | 416.21 | 312.50 | 141.7 | 38.06 |
| % of A | 100 | 126 | 260 | 195 | 88 | 24 |
| Cached (seconds) | 163.1 | 196.12 | 170.28 | 174.10 | 136.83 | 39.13 |
| % of A | 100 | 120 | 104 | 107 | 84 | 24 |

This more exhaustive trial showed the additional computation of reordering outweighed any reduced sampling benefits in the majority of cases. Although pre-calculated orders improved performance, the only real benefits were in the reverse ordering (E), or the hop approach (F). The most impressive reduction coming from the hop method (F). To investigate this, further trials were carried out whereby the hop

distance was adjusted to find an optimum value.

6. Trial 3 – Varying the hop size

To determine the most suitable hop size a set of three further trials were conducted. As before 1000 randomly selected points were used to conduct 1 million visibility tests in Trials 3A and 3B. For Trial 3C a large sample was taken of 2000 points, resulting in 4 million lines of sight. The locations for these trials were centred on different parts of the city (Figure 3). For these trials the hop size was adjusted after each run in an effort to determine the most suitable value.

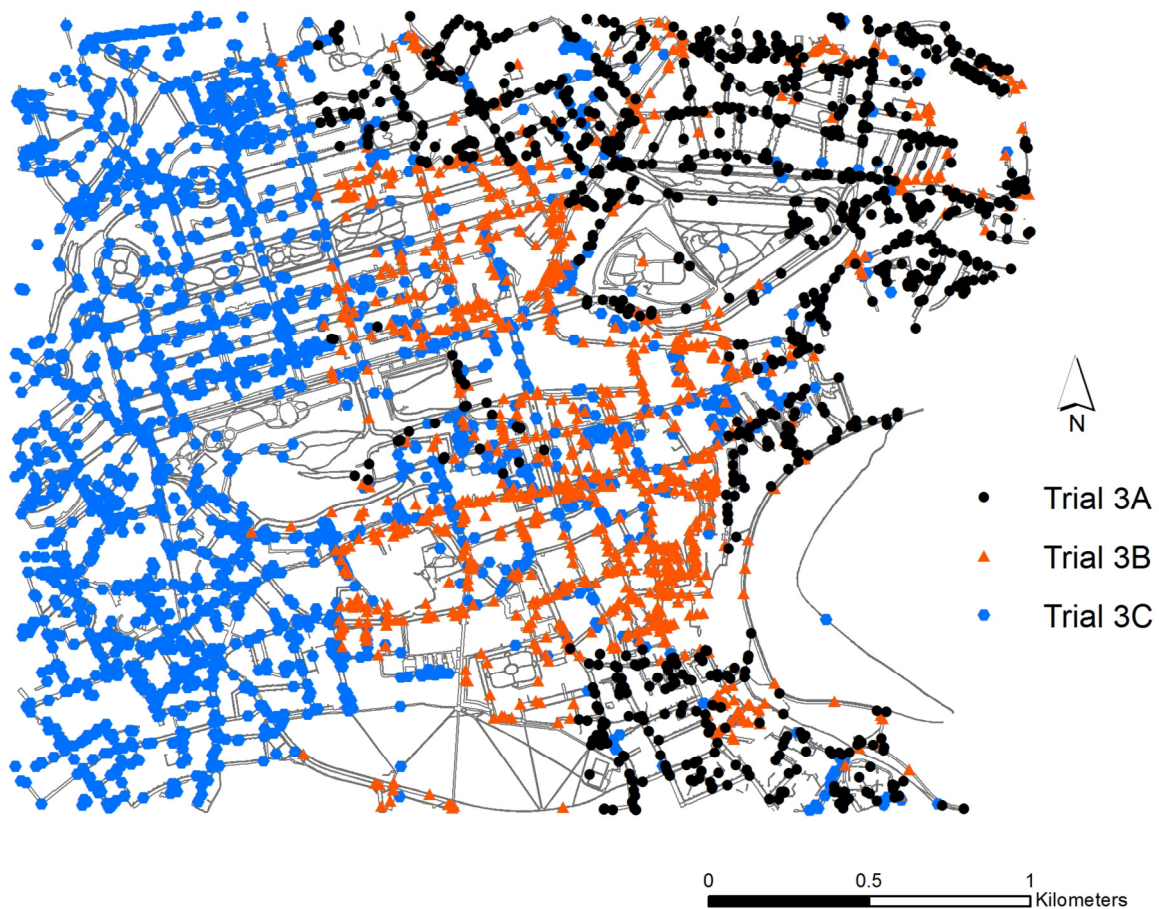


Figure 3: Randomly selected locations in Edinburgh (Scotland) for Trials 3A, 3B, 3C

For larger hop sizes fewer samples are required on each pass but there is an increase in the number of subsequent ‘in filling’ passes to ensure that all the sample locations at the 1 metre resolution of the DSM are sampled (Figure 4). The optimum hop size occurs when there is the highest chance of an early sample resulting in a viewing angle above that of the target, rendering it out of sight allowing for LOS termination.

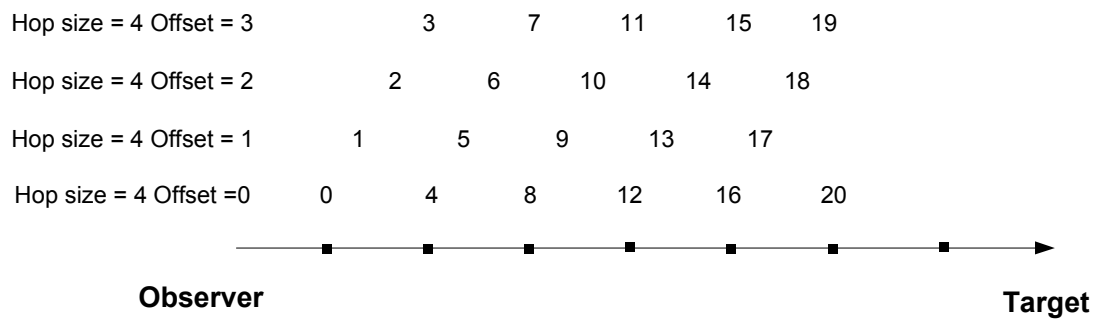


Figure 4: Details of the Hop Size Method

The results from these three trials are shown in Figure 5, and exhibit very similar patterns, whereby the optimum hop size is in the region of 20-40 metres. This would appear to correlate with the scale of roads and buildings within the city region, leading to an early detection of target occlusion. Larger hop sizes lead to a marginal increase in execution time, as more infilling sample locations are required, as outlined in Figure 4.

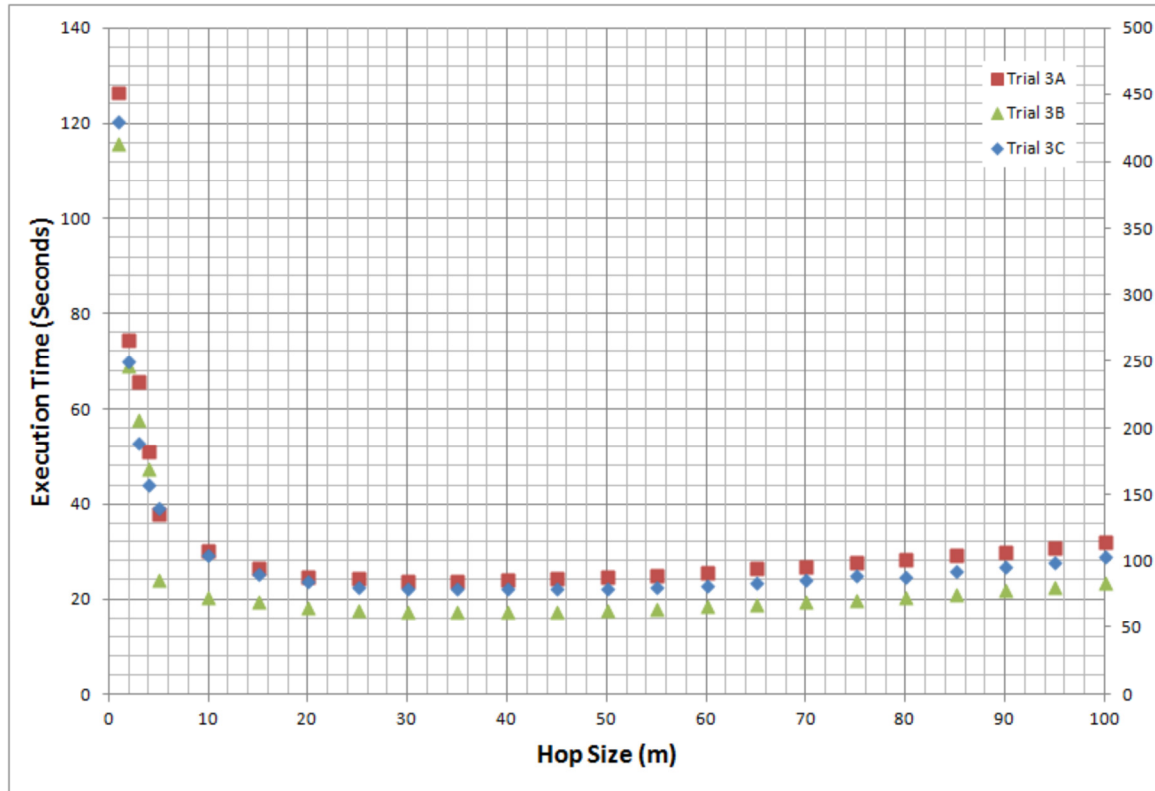


Figure 5: Execution Times with Varying Hop Sizes for Trials (Trial 3C refers to right vertical axis)

A more detailed test for Trial 3A was carried out for hop increments of 1 metre to study in more detail the changes in performance between 20 metre and 40 metre hop sizes. The results show that there is very little difference, but that the slight improvement occurs around 26-29 metres (Figure 6).

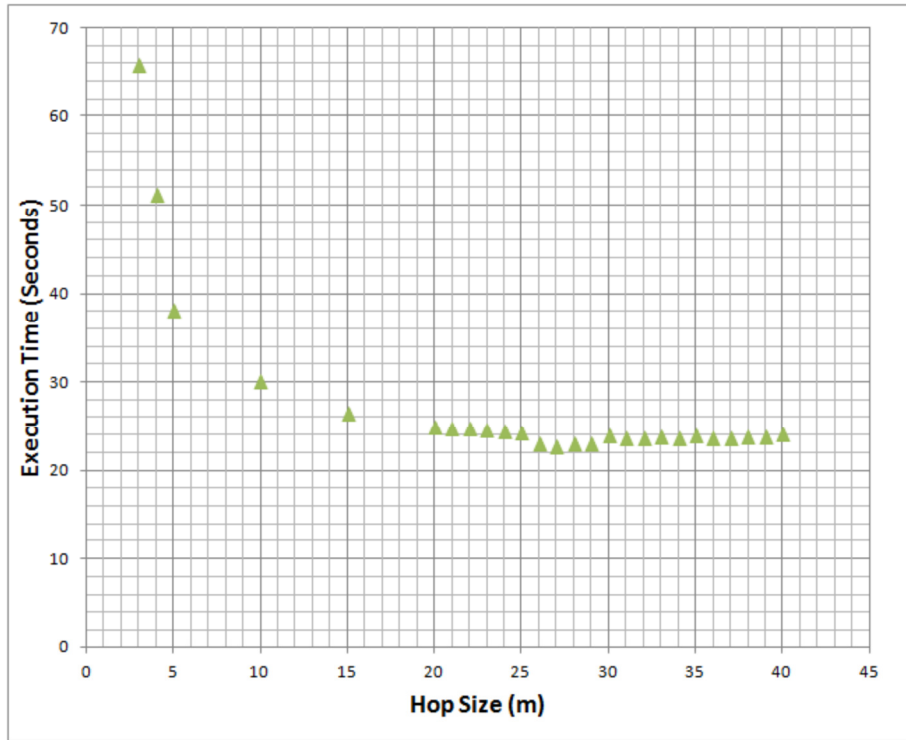


Figure 6: Detailed Examination for Trial 3A

Trial 2 was repeated using a hop size of 27 metres, with a result found in 18.2 seconds, giving an 8 time performance increase from method A.

8. Trial 4 – Varying the Offset Value

There are two variables which can be controlled in the hop method, the hop size and the offset value. The trials conducted so far have varied the hop size but used a consistent offset increment of 1metre, as shown in Figure 4. To determine the most suitable offset sequence a comparison was made between the First/Last Ordering, Divide and Conquer, and Reverse Ordering methods. The results (Figure 7) show that the Reverse ordering approach offered a small performance improvement over the standard 1 metre increment method, and as before the Divide and Conquer increases the computational load in sample ordering.

The marginal improvement noted for the reverse ordering would agree with the overall trend that the shorter hop sizes (under 10 metres) result in longer processing times, and therefore by maintaining higher hop sizes as a priority a better overall performance is possible. As an example of this if a hop size of 25

metres had not determined the target to be obscured, then a follow up ‘in filling’ sample at a distance of 24m from the observer would be more likely to determine the target obscured than a sample 1m in front of the observer.

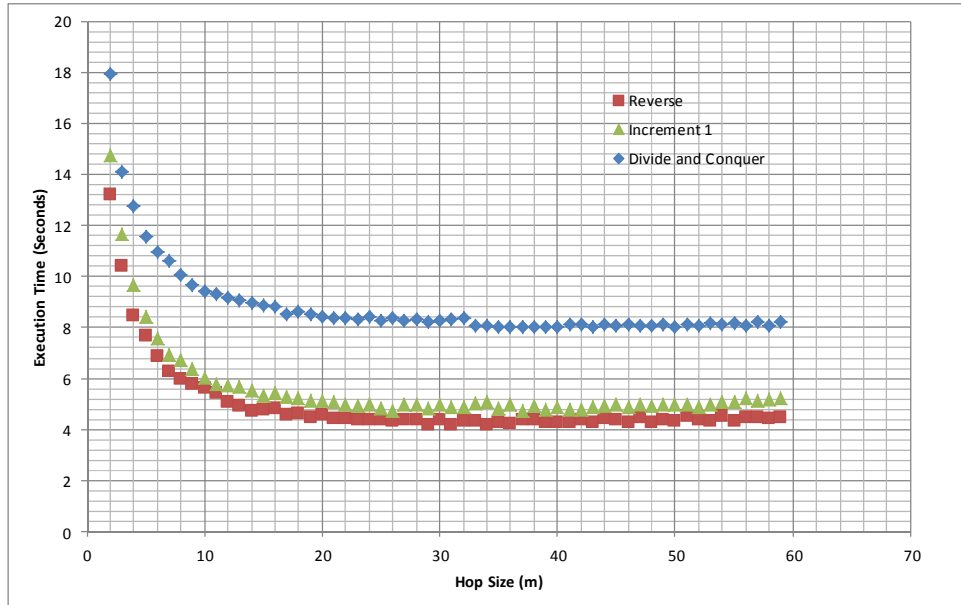


Figure 7: Alternative Offset Methods for the Hop Approach

9. Trials for Other Cities

The optimised line-of-sight method was trialled in two further cities to discover if performance benefits would be noted for similar hop sizes in different regions. The trials were conducted in Birmingham and Nottingham, selected due to the availability of comparable LiDAR datasets. As before 1000 random pedestrian accessible locations were selected around the city (Figure 8), and the intervisibility from each location to all others was calculated.

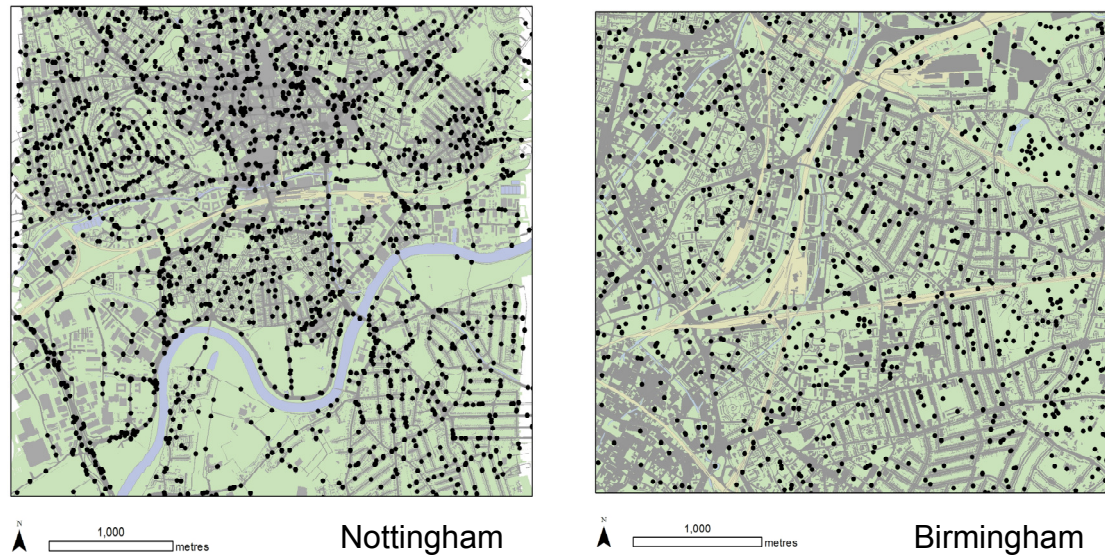


Figure 8: Sample Locations for Birmingham and Nottingham City Trials

(OS Master Map Crown Copyright 2012)

The results indicate a very similar pattern to that noted in Edinburgh, with the optimum hop size of 33 metres for Nottingham, and 29 metres for Birmingham (Figure 9).

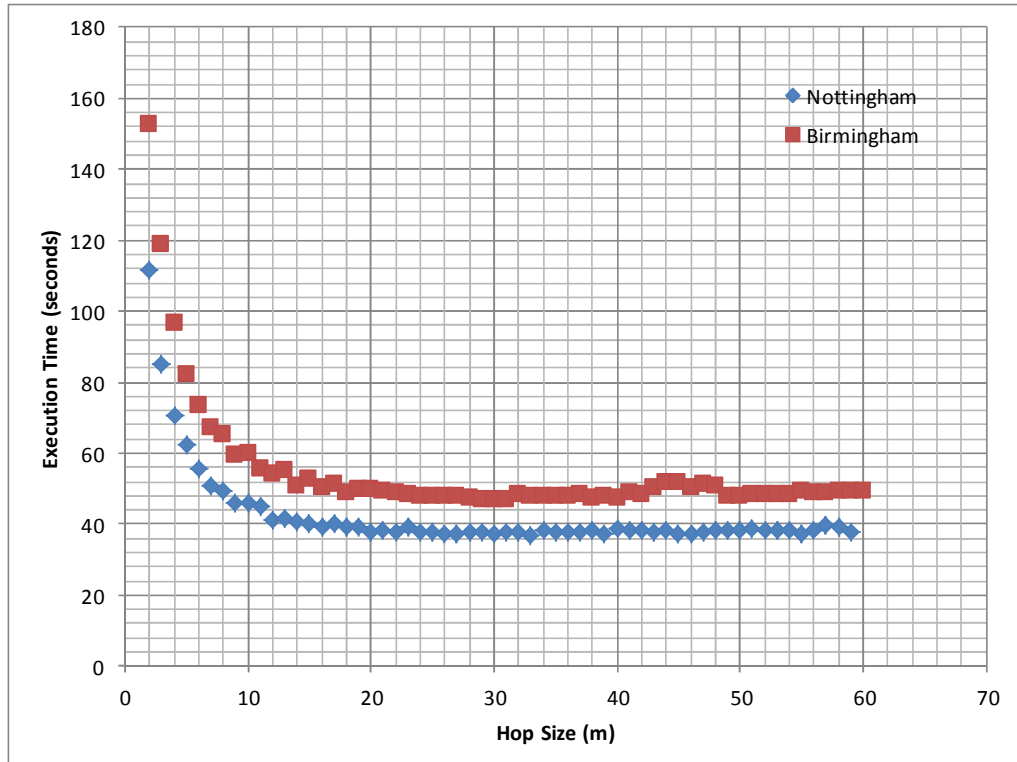


Figure 9: Trials to Determine Optimum Hop Size for Birmingham and Nottingham Cities

A comparison of the processing time for each of the cities reveals the most significant performance increases are made when using a hop size in the 20 metre to 30 metre range. This trend is shown in Table 4, whereby the improvement for a hope size of 10m compared to 5m is around 26% to 37% faster, whereas the improvement from 25m to 30m was negligible (1% to 1.9%). In the cases of Edinburgh and Nottingham the larger hop sizes 35m to 40m yielded a negative benefit, -0.7% and -2.3% respectively.

These trials demonstrate that a hop size between 20 metres and 30 metres yields a positive optimisation for city regions, and that the exact value within this range is of minor importance.

Table 4: Percentage Performance Gain for selected Hop Size Intervals in each City

| City | 5m to 10m | 15m to 20m | 25m to 30m | 35m to 40m |
|------------|-----------|------------|------------|------------|
| Edinburgh | 26.6% | 6.5% | 1.5% | - 0.7% |
| Nottingham | 35.9% | 6.0% | 1.0% | - 2.3% |
| Birmingham | 37.4% | 6.1% | 1.9% | 0.7% |

10. Example Outputs:

As mentioned previously the optimised LOS algorithm can be used in a range of tasks from determining the visibility of upcoming junctions, to determining visibility between nodes in a geosensor network, to notification of points-of-interest in view. *Figure 10* shows the output from using the optimised algorithm for rapid axial line generation (Batty and Rana 2004; Turner 2007). These give an indication of the openness of a space, and the lines of sight in a region. For example Site A (*Figure 10*) is on a cliff top, and the axial lines show graphically the very wide range of viewing angles, and long distances, of objects in view from this location. The openness and interconnectedness of the square at Site B is also apparent, as is the limitation imposed on the east side of Site C by the topography. Elsewhere the much more limited views of the urban corridors are clearly represented.

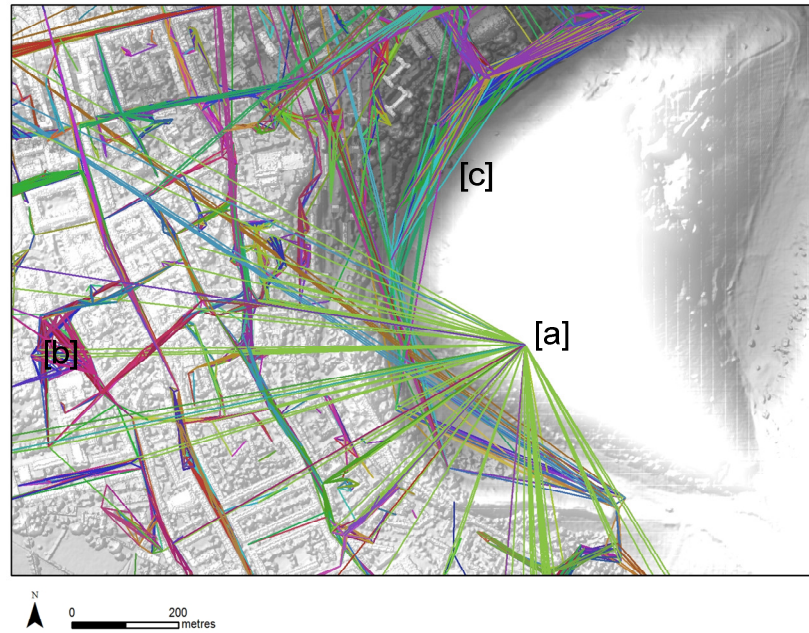


Figure 10: Visible Observer-Target Pairs for part of Edinburgh Trial, on a Hill-Shaded DSM

11. Conclusion

This research has shown that the sampling order in the line-of-sight algorithm plays a significant part in the performance. A number of sample ordering methods were tested with the greatest optimisation possible when using a sampling hop. The hop size was varied from 1 metre to 100 metres, and in 3 separate trials the hop sizes from 20 metres to 40 metres was deemed to be the most efficient, resulting in a performance increase in the order of 8 times. The sequence of the hop method's offset variable was also adjusted, with a reverse method being found to offer the best performance.

The hop method was then trialled in three UK cities to determine the transportability of the model. It was found that in all cases the optimum hop lengths were around 30 metres, with only minimal benefits noted when fine tuning the hop size. Future work should compare the results across a wider range of cities in different parts of the world, and also in more rural areas to determine the range of hop sizes suited to different topographies.

The work has direct benefit in point-to-point visibility analysis, and is particularly pertinent in the context of LBSs where calculations are carried out on mobile devices with more limited processing and

power resources, or in client-server setups where a server may be supporting many concurrent users.

8. Acknowledgements

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8. Biography

Phil Bartie completed his PhD at the University of Canterbury (NZ) before recently moving to The University of Edinburgh to work on the EU funded SpaceBook project. William Mackaness is a lecturer in the School of GeoSciences. Their mutual research interests are in location based services – specifically in the context of dialogue based interaction.